Lithography Light Source Fault Detection

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ABSTRACT

High productivity is a key requirement for today's advanced lithography exposure tools. Achieving targets for wafers per day output requires consistently high throughput and availability. One of the keys to high availability is minimizing unscheduled downtime of the litho cell, including the scanner, track and light source. From the earliest eximer laser light sources, Cymer has collected extensive performance data during operation of the source, and this data has been used to identify the root causes of downtime and failures on the system. Recently, new techniques have been developed for more extensive analysis of this data to characterize the onset of typical end-of-life behavior of components within the light source and allow greater predictive capability for identifying both the type of upcoming service that will be required and when it will be required.

The new techniques described in this paper are based on two core elements of Cymer's light source data management architecture. The first is enhanced performance logging features added to newer-generation light source software that captures detailed performance data; and the second is Cymer OnLine (COL) which facilitates collection and transmission of light source data. Extensive analysis of the performance data collected using this architecture has demonstrated that many light source issues exhibit recognizable patterns in their symptoms. These patterns are amenable to automated identification using a Cymer-developed model-based fault detection system, thereby alleviating the need for detailed manual review of all light source performance information. Automated recognition of these patterns also augments our ability to predict the performance trending of light sources.

Such automated analysis provides several efficiency improvements for light source troubleshooting by providing more content-rich standardized summaries of light source performance, along with reduced time-to-identification for previously classified faults. Automation provides the ability to generate metrics based on a single light source, or multiple light sources. However, perhaps the most significant advantage is that these recognized patterns are often correlated to known root cause, where known corrective actions can be implemented, and this can therefore minimize the time that the light source needs to be offline for maintenance. In this paper, we will show examples of how this new tool and methodology, through an increased level of automation in analysis, is able to reduce fault identification time, reduce time for root cause determination for previously experienced issues, and enhance our light source performance predictability.

Keywords: light source, fault detection and classification, availability

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1. Introduction

The increasing cost sensitivity of semiconductor manufacturing is driving significant attention towards equipment uptime and availability. Particularly in leading edge lithography processes, the demand for uptime and availability cascades down to the litho tools which are the designed constraint in the manufacturing workflow. Improving uptime and availability means reducing equipment downtime, where downtime includes preventative maintenance and replacement of consumables, see SEMI E10 Standard [1] illustrated in Figure 1. Furthermore, one of the key elements in maximizing the availability efficiency is to minimize unscheduled downtime. While one solution would be to proactively replace consumables well before they cause unscheduled down time, the cost associated with premature replacement will negatively impact the overall operating costs.

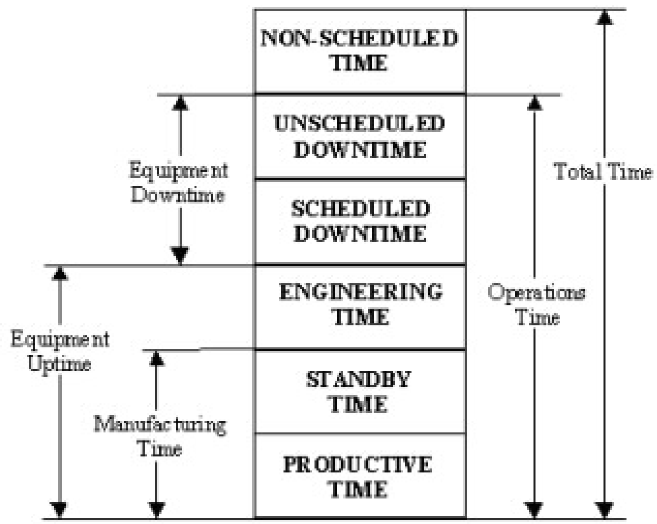

Figure 1: Breakdown of SEMI E10 standard (*Specification for Definition and Measurement of Equipment Reliability, Availability, and Maintainability*.)

Minimizing unscheduled downtime requires data to provide detailed analysis about tool performance to extend the consumable use and avoid premature replacements. In order to provide up-to-date information for troubleshooting and scheduling maintenance, while minimizing impact to the manufacturing process, tool performance data is collected on-line under production conditions. From the earliest excimer light sources, Cymer has collected extensive performance data from light sources that have been used to identify root cause for failures and create action plans for preventative maintenance. Recently, new techniques have been developed for more advanced automated data analysis to characterize the onset of end-of-life behavior of consumables and allow greater predictive capability for identifying when and what type of service will be required.

Comprehensive analysis of the performance data collected using this architecture has demonstrated that many light source issues exhibit recognizable patterns in their symptoms. These patterns are amenable to automated identification using a Cymer-developed model-based fault detection and classification (FDC) system, thereby alleviating the need for detailed manual review of all light source performance data. Furthermore, automated recognition of these patterns also augments the ability to predict performance trend of light sources.

Such automated analysis provides several efficiency improvements for light source troubleshooting and preventative maintenance scheduling by providing more content-rich standardized summarization of light source performance along with reduced time-to-identification for previously classified faults. Automation provides the ability to generate light source performance metrics based on the performance of a single light source, or of multiple light sources. However, perhaps the most significant advantage is that these recognized patterns are often correlated to a known root cause, where known corrective actions can be implemented. This can minimize the time that the light source needs to be offline for maintenance.

This paper presents the Cymer model-based FDC tool used to enhance light source service strategy. An example of the tool use is provided to demonstrate the FDC methodology. Through an increase level of automation in data analysis, Cymer is able to realize reduced troubleshooting time for previously experienced issues and hence improve light source performance predictability.

2. Data Management Architecture for Fault Detection and Classification

Fault detection identifies that an operating condition is different from normal, while classification identifies what caused the difference. The fault detection and classification techniques described in this paper are based on two core elements of the Cymer light source data management architecture. The first is enhanced performance logging features added to current-generation light source software that captures detailed performance data synchronous with detection of fault conditions. The on-board logging capability is responsible for the on-line monitoring of performance. During normal operation, on-board logging mostly consists of time-based average performance data. However if a fault condition is detected, on-board logging captures detailed performance data around the fault condition.

The second core element of the Cymer light source data management architecture is Cymer OnLine (COL), which facilitates the collection, transmission, and storage of light source performance data for classification analysis. Most performance data is processed outside the light source software in order to provide the highest quality data analysis, since expert service engineers consider all current information regarding known operating conditions and performance issues. Similarly, the automated classification analysis is performed on a data analysis server to take advantage of central processing and rapid access to updated information. By relying on a centralized performance analysis structure, ongoing improvements and refinements of the FDC tools can be quickly implemented without disturbing the fielded light sources. A diagram of the current service work flow, including automated data analysis, is presented in Figure 2.

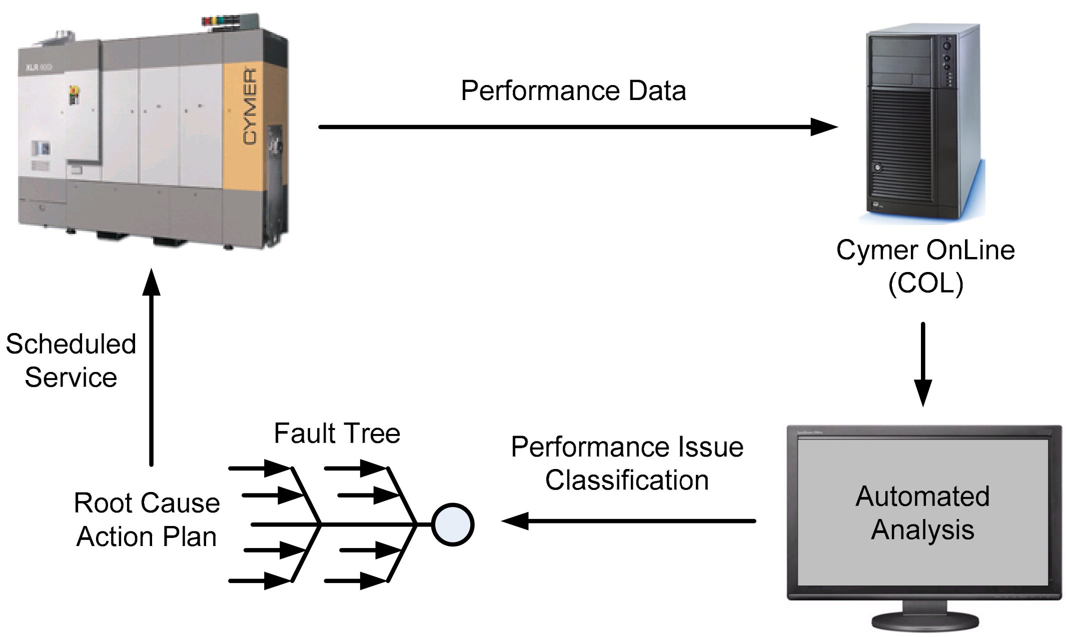

Figure 2: Flow diagram for Cymer FDC architecture. Performance data is created on-board the light source then transmitted and collected by COL. Automated analysis classifies the performance issue, which is then used to assign root cause and determine the appropriate action plan for service.

Prior to the existence of the automated data analysis discussed in this paper, performance data was directly accessed by service engineers who interpreted information contained in the data. Automated data analysis

enhances this service strategy by interpreting raw performance data into information about the health of the light source. This additional information is readily available to service engineers for developing actions and scheduling maintenance activities. The Cymer FDC was developed such that whenever applicable a one-to-one relationship is established between the performance issue and final root cause (see fault tree presented in Figure 3). Several levels of classification analysis exist, the primary level designates the performance issue to a category while subsequent levels narrow down the performance issue to the eventual root cause. In case a root cause can not be determined, perhaps due to lack of fault excitation and observability in the data set, then an issue category is assigned and manual troubleshooting can be directly applied to resolve that section of the fault tree.

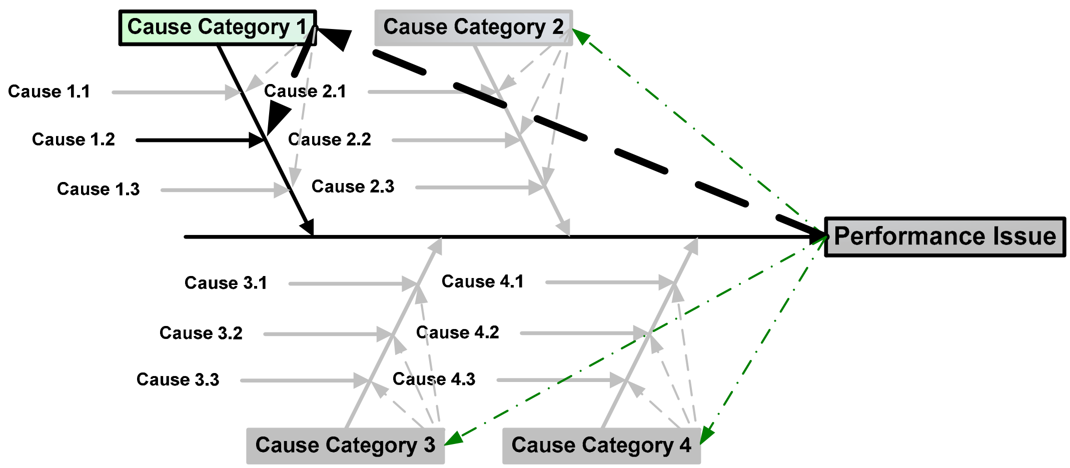

Figure 3: Diagram of a fault tree documenting possible root causes for performance issues. Several category levels within the fault detection and classification provide a relationship that leads between the performance issue and root cause.

Finally, automated analysis is capable of processing much larger quantities of data, enabling a greater understanding of light source performance with respect to population statistics as well as rapid development of issue resolution strategies. Furthermore, this augments the ability to predict the trend of light source performance and therefore minimize downtime and resources required for maintenance.

3. Fault Detection and Classification Methodology

Different approaches for fault detection and classification using mathematical models have been developed over many years [2]. These methods augment the more general statistical pattern recognition techniques, see [3] and references therein, particularly where information about the process is known and useful for constructing a process model. Model-based approaches use prescribed dependencies between different measured signals that are expressed in mathematical models in order to select relevant variables in the performance data. Feature extraction is the process of mapping original measurements into more useful features. Relevant features might correspond to the operation of sensors, actuators or subsystems of a process.

Important features in light source performance data are typically non-linear mapping functions of the original measurements. The feature extraction mappings are based on mathematical models of light source operation, developed to amplify characteristics that are expected under certain fault conditions. An example nonlinearity included into feature extraction models is signal processing logic that explicitly considers performance transients between operating modes. In most cases, the signal processing involves constructing multivariate signals to form effective feature extraction mappings that are metrics of light source performance.

An effective feature extraction mapping is one that correctly indicates the likelihood of the presence of recognizable symptoms of a particular fault condition. The likelihood of a fault above a specified threshold determines the detection and classification of the fault condition. The Cymer fault analysis software is built

upon a flexible infrastructure that enables rapid development and deployment of feature extraction mappings. Training data sets are used to evaluate feature extraction mappings over numerous light source operating conditions for effective and reliable identification of a particular fault condition. Once validated, newly developed features are easily deployed to the mainstream automated analysis software. Since the architecture relies on a centralized analysis function, software that resides on the fielded light sources does not need to be modified, and the implementation can be immediate.

For each light source performance data set received, multiple features can be extracted. The automated data analysis classifies the data set into a fault condition by observing all the extracted features and quantifying any discrepancies from expected behavior. Some fault conditions are amenable to single features that directly relate to root cause, while others require correlation of several features in order to recognize a pattern that indicates root cause. In either case, the automated analysis provides consistent information that reduces the reliance on expert service engineer judgment in identifying the correct resolution for a performance issue.

3.1 Case Study

The following case study provides an example for the methodology of the Cymer model-based FDC. The maximum pulse-to-pulse energy exceeds a specified threshold and triggers the fault condition (see Figure 4). Once the fault condition is detected, light source performance data is collected and transmitted for analysis as described in Section 2. Performing single-variate analysis, that is considering one signal at a time, the cause for the performance issue often can not be identified. Indeed several key signals, shown in Figure 5 – a and 5 – b, are well within their normal variation leading up to the fault condition.

Here it may be interesting to note that the fault condition presented in this case study is considered a rare occurrence. Particularly in known but rarely occurring fault events, detailed analysis beyond the readily available performance data (single-variate signals) would have required time and resources before issue resolution. Automating the data analysis expedites the troubleshooting processing by quickly delivering the relevant information about the fault symptoms regardless of how often the fault condition actually occurs.

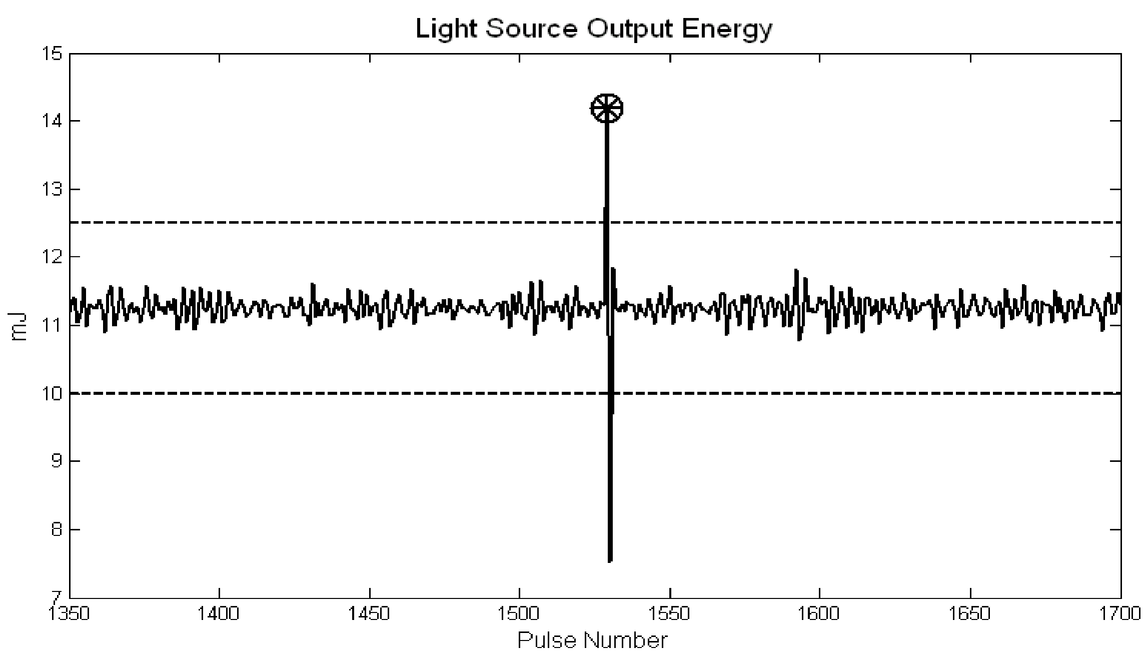

Figure 4: Light source measured output energy (solid line) is plotted against the pulse-to-pulse energy fault condition (dotted line). A pause in light source operation is indicated by the circle (O) which coincides with the first pulse to exceed the threshold designated by the marker (*).

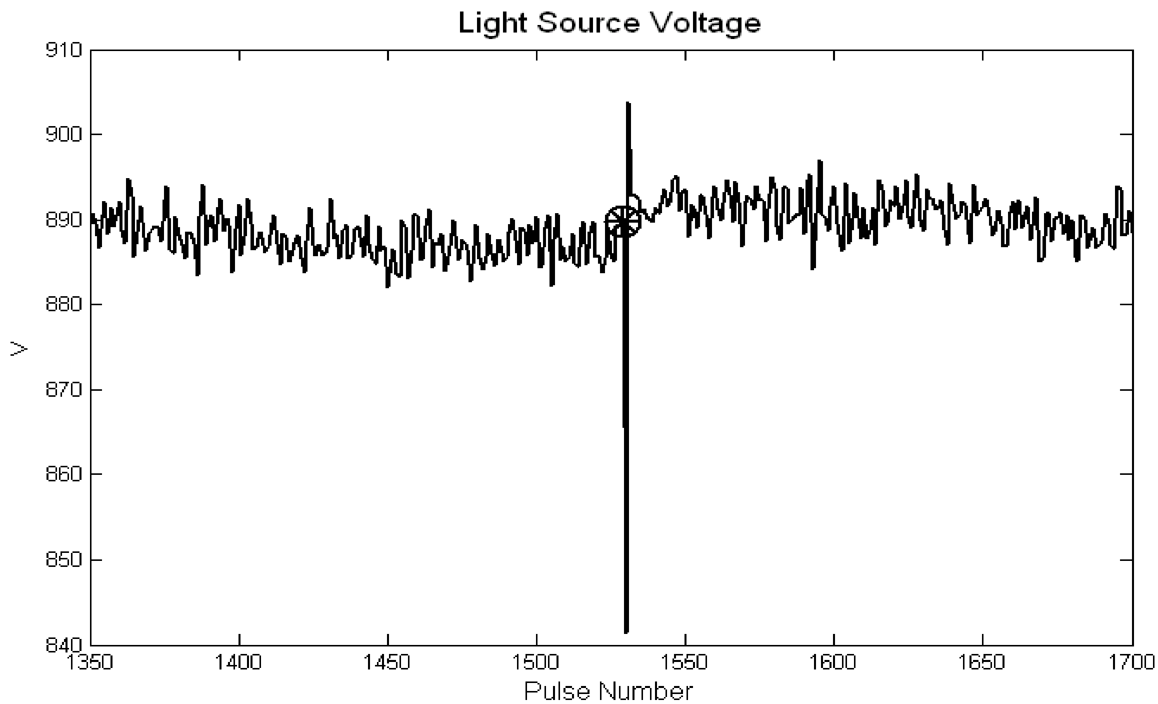

Figure 5 – a: Light source measured input voltage (solid line). A pause in light source operation is indicated by the circle (O) which coincides with the first pulse to exceed the threshold designated by the marker (*).

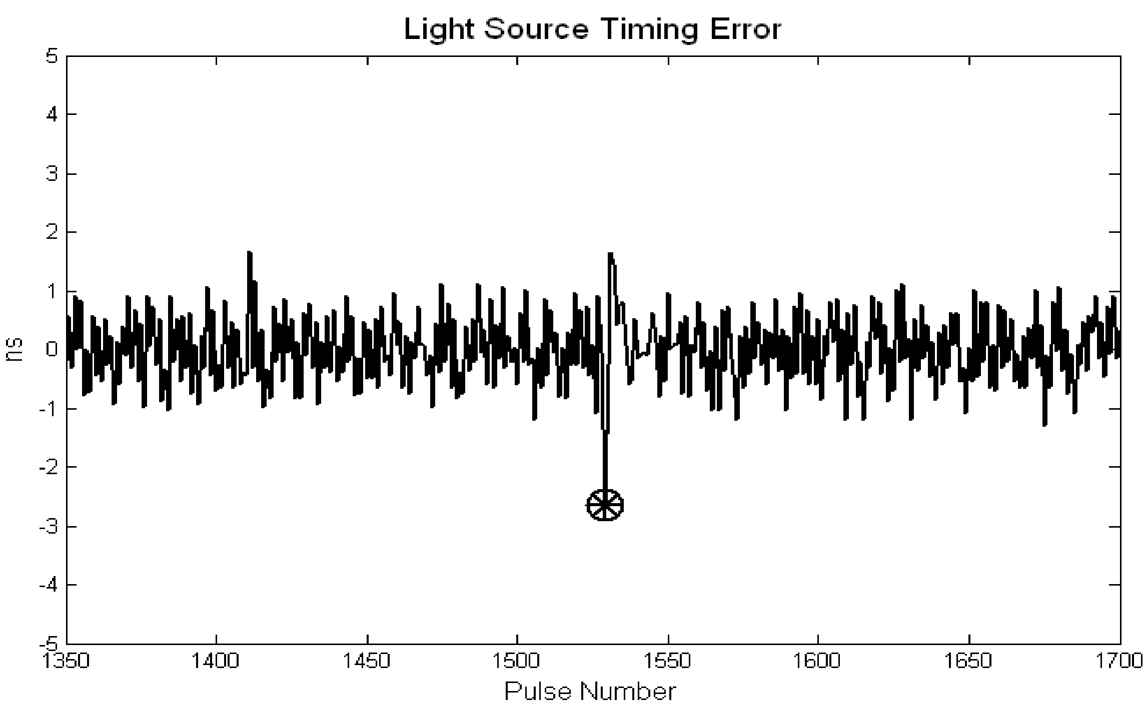

Figure 5 – b: Light source measured timing error (solid line). A pause in light source operation is indicated by the circle (O) which coincides with the first pulse to exceed the threshold designated by the marker (*).

The collected fault condition performance data is evaluated over multiple feature extraction models of the light source that are built in to the FDC system. For this case study example, one extracted feature exhibits sufficient information to identify root cause. This feature relates the signals shown in Figures 5–a and 5–b via mathematical model of the light source physics.

The constructed multivariate signal, plotted in Figure 6 as a function of light source voltage, clusters the expected light source performance along a single line. Discrepancies from expected performance are clearly visible from this representation of this visualization of the data, however it does not yet indicate a root cause for the fault condition. The relevant feature for this particular fault condition is a projection of anomalous data points onto the light source model. The projected value is the expected voltage driving the light source inferred from other measurements of light source performance, i.e. that there is a discrepancy between the reported voltage and the one actually applied to the light source. The projected discrepancy indicates a rare occurrence on legacy software versions, whereby an internal software deadline is not met, and the applied voltage is incorrect. The issue is quickly resolved by recognizing the root cause for the fault condition and upgrading software.

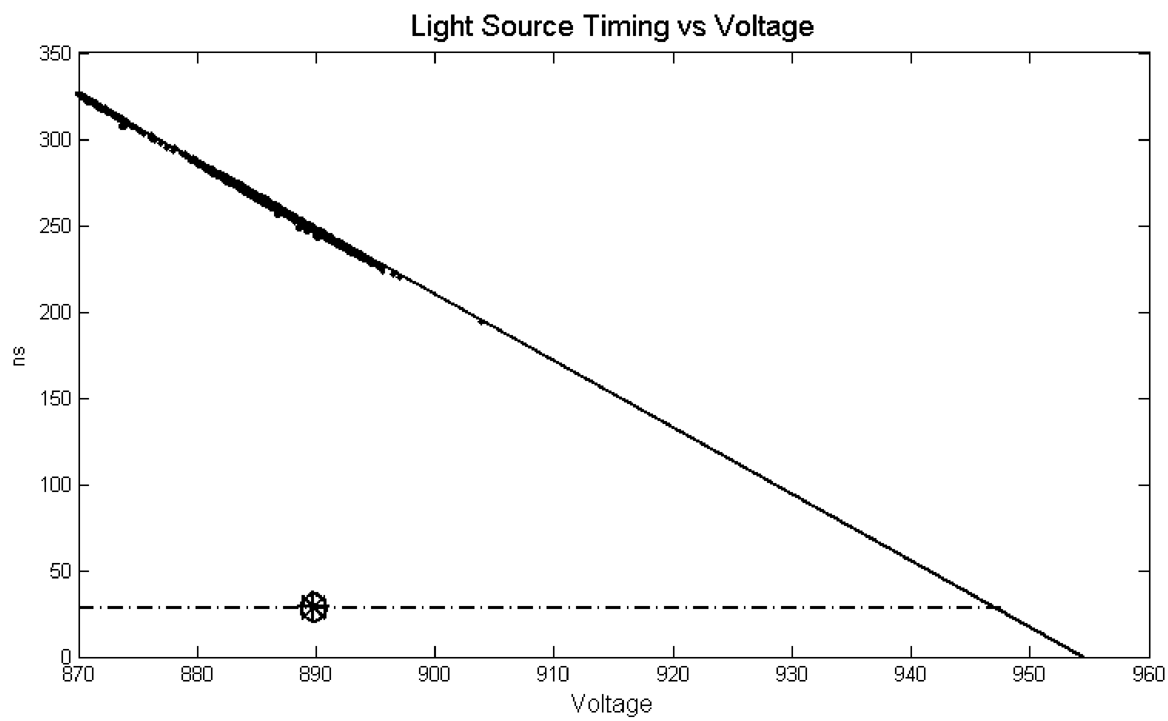

Figure 6: Light source measured output energy (solid line) is plotted against the pulse-to-pulse energy fault condition (dotted line). A pause in light source operation is indicated by the circle (O) which coincides with the first pulse to exceed the threshold is designated by the marker (*).

4. Fault Detection and Classification Performance

The Cymer FDC system was first tested and released in January 2009. Currently the automated data analysis is processing performance data from more than 300 fielded light sources around the world and approximately 1 [Gbyte] per day. On average, 60% of the performance issues detected by each light source are classified according to the symptoms displayed in the performance data during the fault condition, see Figure 7. Although not each classification implicates the fault condition root cause, the analysis adds information by identifying or ruling out symptoms of the fault condition.

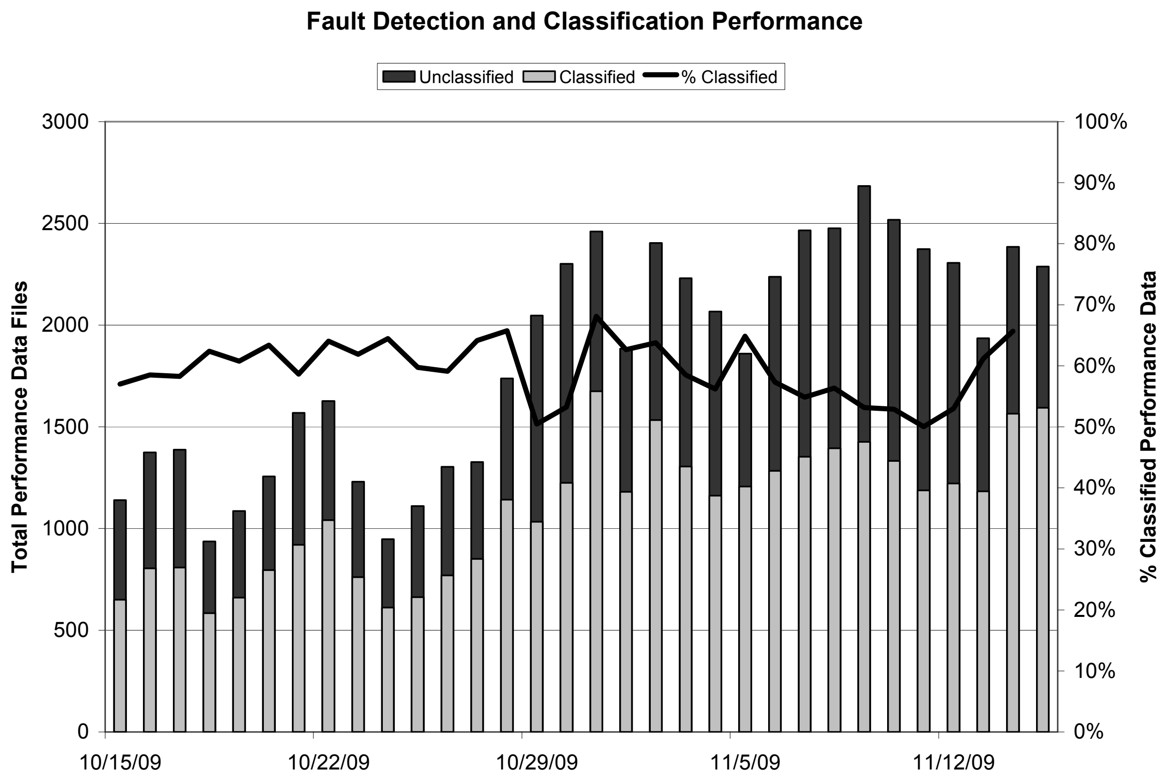

Figure 7: FDC performance in monitoring all fielded Cymer light sources. On average, 60% of performance issues are classified.

As mentioned in Section 2, the Cymer FDC system enhances current service strategy and augments the ability to predict the performance trending of light sources. Many fault conditions progress with operation of the light source, thus by monitoring the performance data issues can be recognized and addressed more accurately and with more time to prepare scheduled maintenance action plans. Consider for example the performance issue presented in Figure 8. The fault condition was automatically identified prior to customer impact and the appropriate action plans were developed and ready for the next scheduled maintenance opportunity. The performance issue caused by the fault condition was resolved during scheduled maintenance, reducing the impact to production.

As a part of an overall service strategy, automated FDC augments the ability to predict the performance trending of light sources. The impact of augmenting performance predictability can be observed in comparing scheduled versus unscheduled downtime. Cymer Technical Support deployed a Proactive Service Program (PSP) in conjunction with FDC in December 2008. The FDC system adds information performance summaries for each light source. Figure 9 shows the monthly scheduled versus unscheduled events for one customer participating in this program. Shortly after deployment, the ratio between scheduled versus unscheduled service improved by 10%. While there are many factors that contribute to this improvement, FDC enhances the capabilities and value of the Cymer PSP program.

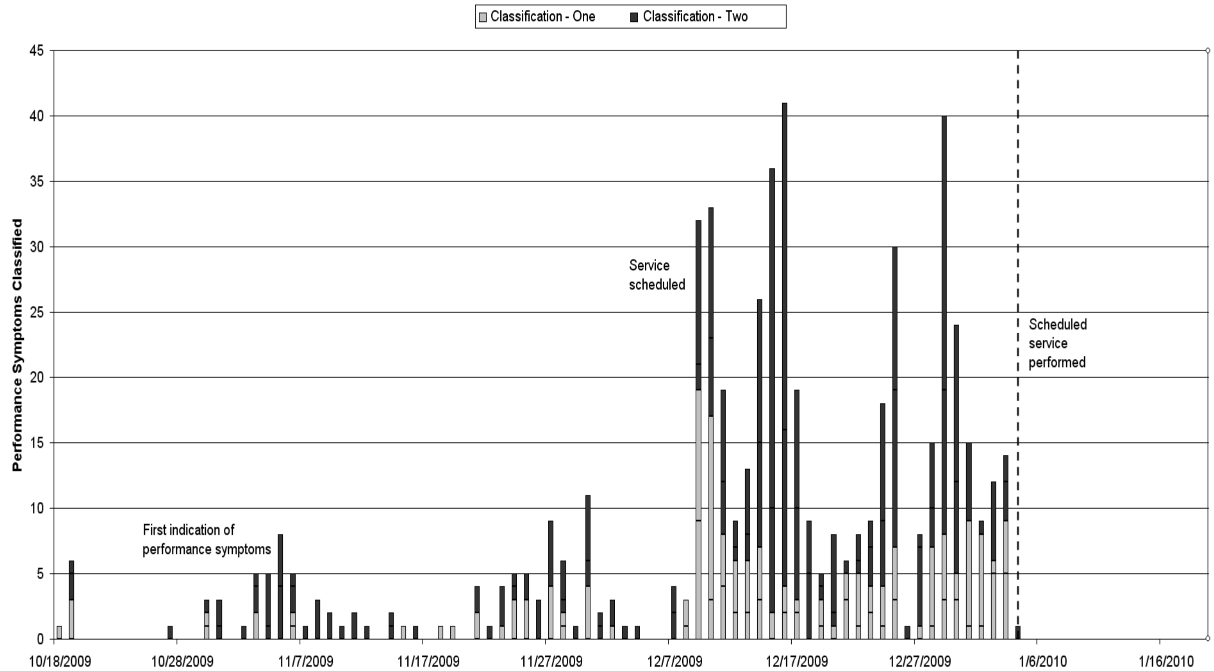

Figure 8: FDC summary for a single light source during the progression of performance symptoms. The performance symptoms begin with small low rate of events that increase in frequency over time. Two classification types, which are related to a single light source subsystem, have been identified. In this case, automated classification enabled awareness of the performance issue root cause with sufficient time to schedule maintenance with two week horizon.

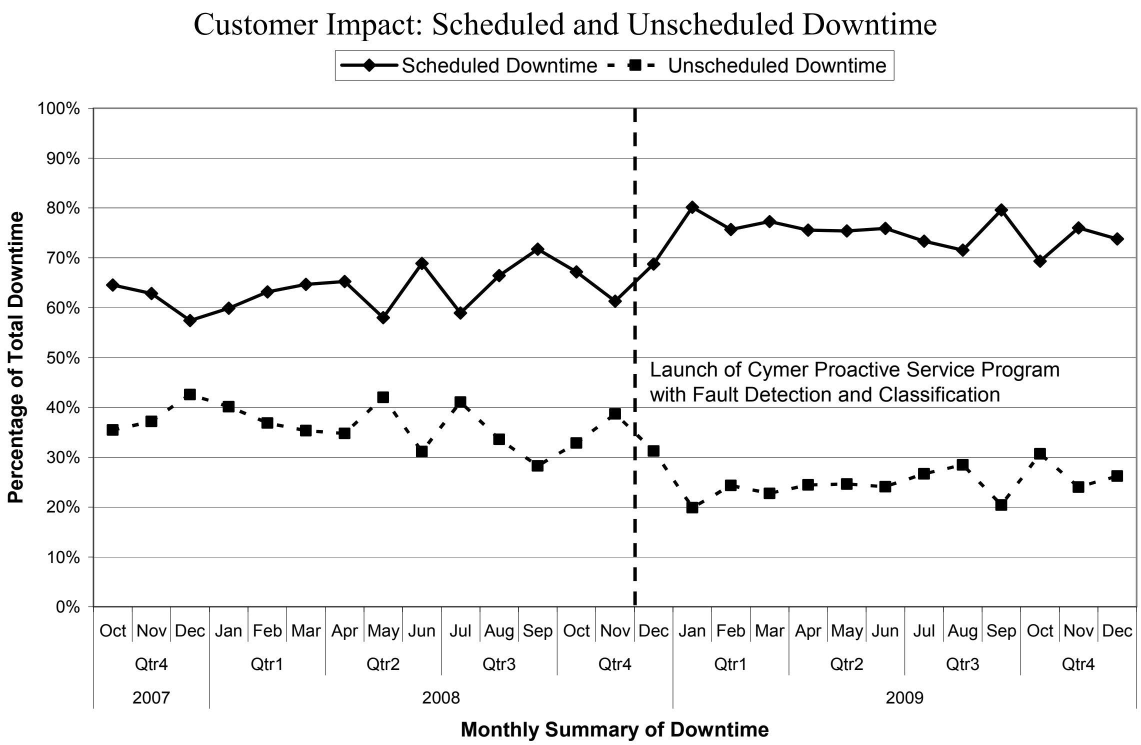

Figure 9: Single customer comparison of scheduled versus unscheduled downtime that shows the improvement in scheduled service with the deployment of Proactive Service Program (PSP) in conjunction with FDC.

5. Conclusions and Future Work

Cymer FDC provides several efficiency improvements for light source troubleshooting by providing more content-rich standardized summaries of light source performance along with reduced time-to-identification for previously classified faults. Perhaps the most significant advantage is that performance issues that exhibit recognized patterns are often correlated to known root cause, where known corrective actions can be implemented. This is therefore used to schedule service activities and minimize the impact of the duration of time that the light source is offline for maintenance. Through an increased level of automation in analysis, Cymer is able to reduced fault identification time, reduce time for root cause determination for previously experienced issues, and enhance light source performance predictability.

References

[1] SEMI E10 - for Definition and Measurement of Equipment Reliability, Availability, and Maintainability.

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[3] Jain, A.K., Duin, R.P.W., Mao, J. “Statistical pattern recognition: A review” IEEE Transactions on Pattern Analysis and Machine Intelligence, 22 (1), 4-37, (2000).